LETTERS TO THE EDITOR

Discharge Coefficient of Bingham Fluid

Editor, Can. J. Chem. Eng.:

Authors Y. C. Yen and C. Tien (Can. J. Chem. Eng., **41**, 83 (1963) present an expression for the discharge coefficient of a jet of a Bingham plastic fluid issuing from a capillary tube under steady laminar flow conditions. The method used was developed by Hagenbach[1] and applied by Gaskins and Philippoff[1] to arrive at an expression for the discharge coefficient of a pseudoplastic fluid. Yen and Tien performed the calculation for a Bingham fluid defined by the shear stress-shear rate relationship

$$\tau - \tau_y = \beta\left(-\frac{dv}{dr}\right) \quad \text{.................(1)}$$

An expression for the kinetic energy flux of the jet stream is utilized in the method which contains the radius of the capillary in lieu of the radius of the free-flowing jet. If the actual radius of the jet is used, then it can be shown that the following expression is obtained for evaluation of the discharge coefficient

$$C_v = \frac{r_o v_o^{3/2}}{\left[2\int_o^{r_o} v^3\, r dr\right]^{1/2}} \quad \text{....................(2)}$$

Applying Equation (2), the expression obtained for the discharge coefficient of a Bingham fluid is given by

$$C_v = \frac{\left(1 + \frac{2}{3}C + \frac{1}{3}C^2\right)^{3/2}}{\left(2 + \frac{116}{35}C + \frac{94}{35}C^2\right)^{1/2}} \quad \text{..............(3)}$$

and, similarly, for a "power-law" pseudoplastic fluid

$$\tau = K\left(-\frac{dv}{dr}\right)^n,$$

the expression obtained is

$$C_v = \frac{\left(\frac{1+n}{1+3n}\right)^{3/2}}{\left(1 - \frac{6n}{1+3n} + \frac{6n}{2+4n} - \frac{2n}{3+5n}\right)^{1/2}} \quad \text{........(4)}$$

In the case of a Newtonian fluid, the predicted discharge coefficient is 0.7070 as compared with the previous value of 0.7937. These two values serve to indicate the effect of the correction on the evaluation of the discharge coefficient by this method.

In view of the simplifying assumptions which were necessitated in the energy balance analysis to permit one to arrive at an explicit relation for the discharge coefficient, the discharge coefficient predicted by this method is only an approximation. An analogous approximate result ($C_v = 0.75$, in the case of a Newtonian fluid) is also derivable based on momentum considerations[2]. Middleman and Gavis[3] present more complete analyses of the energy and momentum balance for a Newtonian fluid which allow for observed expansions as well as contractions of the jet stream and also for variation of the discharge coefficient with the conditions of ejection. However, without specific information concerning the dissipation function or the integral of the normal stress at the capillary exit, one cannot predict the dependence of C_v on *Re*. A correlation of their experimental data yielded an empirical relationship between the dissipation function and Reynold's number. Metzner *et al*[4,5] also present a rigorous analysis involving the conservation of momentum. However, an expression for evaluating normal stresses from capillary jet measurements was the object of their study.

An examination of available data indicates that the discharge coefficient predicted by Equation (2) is low, the deviation decreasing with increasing Reynolds number. For example, the data of Middleman and Gavis indicate a minimum value of 0.77 compared with the predicted of 0.707. The expressions should be of some use in estimating the effect of variations in n or C on the discharge coefficient.

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William Kozicki,
K. S. Yuan,
Department of Chemical Engineering,
University of Ottawa,
Ottawa, Ont.

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William Kozicki,
K. S. Yuan,
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